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Running Head: Stakeholder priorities for multi-functional coastal defences

Title: Stakeholder priorities for multi-functional coastal defence developments and steps to effective implementation

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STAKEHOLDER PRIORITIES FOR MULTI-FUNCTIONAL COASTAL DEFENCE DEVELOPMENTS AND STEPS TO EFFECTIVE IMPLEMENTATION

HIGHLIGHTS

- Stakeholders expressed support for implementing multi-functional coastal defences
- Ecological secondary benefits were favoured over socio-economic and technical ones
- A strategy for implementing multi-functional coastal defence projects is proposed

Abstract

To fulfil international conservation commitments, governments have begun to recognise the need for more proactive marine planning policies, advocating sensitive engineering design that can deliver secondary benefits above and beyond the primary purpose of developments. In response, there is growing scientific interest in novel multi-functional coastal defence structures with built-in secondary ecological and/or socio-economic benefits. To ensure research efforts are invested effectively, it is first necessary to determine what secondary benefits can potentially be built-in to engineered coastal defence structures, and further, which of these benefits would be most desirable. It is unlikely that secondary benefits are perceived in the same way across different stakeholder groups. Further, their order of priority when evaluating different options is unlikely to be consistent, since each option will present a suite of compromises and trade-offs. The aim of this study was to investigate stakeholder attitudes towards multi-functional coastal defence developments across different sector groups. A preliminary questionnaire indicated unanimous support for implementing multi-functional structures in place of traditional single-purpose ones. This preliminary survey informed the design of a Delphi-like study, which revealed a more nuanced and caveated level of support from a panel of experts and practitioners. The study also elicited a degree of consensus that the most desirable secondary benefits that could be built-in to developments would be ecological ones – prioritised over social, economic and technical benefits. This paper synthesises these findings, discusses the perceived barriers that remain, and proposes a stepwise approach to effective implementation of multi-functional coastal defence developments.

Keywords: Coastal protection; Delphi technique; Green infrastructure; Multi-functional; Natural capital; Stakeholder perceptions

1. Introduction

Climate change is leading to rising and stormier seas, increasing coastal erosion and flood risks (IPCC 2014). In response, natural coastlines around the world are being replaced and reinforced by hard engineered structures such as seawalls, breakwaters and groynes (hereafter 'coastal defence structures'; Koike 1996, Davis et al. 2002, Chapman and Bulleri 2003, Airoldi and Beck 2007, Cooper et al. 2016). The negative environmental impacts of these structures have been reasonably well-studied. In addition to direct loss and disturbance of species and habitats (Martin et al. 2005, Dugan et al. 2008), coastal defences can degrade natural landscapes (Burcharth et al. 2007), facilitate the spread of non-native species (Ruiz et al. 2009, Mineur et al. 2012, Airoldi et al. 2015, Bishop et al. 2016, Heery et al. 2016), and alter coastal processes, often with unintended knock-on effects elsewhere (Burcharth et al. 2007, Govaerts and Lauwaert 2009). Further, these artificial structures tend to be poor-quality habitats, supporting depauperate (Chapman 2003, Moschella et al. 2005, Firth et al. 2013b, 2016b) and 'non-natural' (Chapman and Bulleri 2003, Moschella et al. 2005) communities. Soft engineering approaches such as beach replenishment, sand dune stabilisation and managed realignment are widely considered to be more sustainable options for flood and erosion risk management (Capobianco and Stive 2000, Turner et al. 2007, Govaerts and Lauwaert 2009, Temmerman et al. 2013, Hanley et al. 2014). These practices do also, however, carry considerable and often-overlooked environmental implications (Nordstrom et al. 2000, Nordstrom 2005, Peterson and Bishop 2005), and may prove to be unsustainable over time (McNamara et al. 2011). Nevertheless, in scenarios where no alternative options are viable for protecting people, property and infrastructure, shoreline management policies continue to recommend a strategy of 'hold the line' (e.g. in the UK: Environment Agency 2009). This means that local authorities will be required to maintain existing defences and potentially implement additional 'hard' protection measures.

In order to fulfil international marine conservation commitments (laid out in the OSPAR Convention and the Convention on Biological Diversity; also see Naylor et al. 2012 for an outline of some relevant European and UK legal instruments), governments have begun to recognise the need for more proactive marine planning policies and legislation. This study focuses on UK planning policies and stakeholders, but similar challenges are being faced across Europe and the world (Nicholls and Tol 2006, Hanson et al. 2011, Hinkel et al. 2014). The UK's Marine Policy Statement (HM Government 2011) advises that in addition to avoiding harm to marine ecology and biodiversity (§2.6.1.3), developments also "*may provide, where appropriate, opportunities for building-in beneficial features*" (§2.6.1.4). Although not prescribing a definitive obligation, this clearly advocates sensitive engineering design that can deliver secondary benefits above and beyond the primary purpose of developments – in the context of this study, coastal protection.

To date, there are few examples of truly and purposefully-designed multi-functional coastal defences around the world (but see Mead and Black 1999, Harris 2003, Jackson et al. 2012, Mendonça et al. 2012, Stive et al. 2013, Scyphers et al. 2015, Perkol-Finkel and Sella 2016). Single-purpose artificial reefs have been implemented to provide habitat for commercial fish species (Santos and Monteiro 1997, Spanier et al. 2010), to enhance marine biodiversity (Ambrose 1994, Allemand et al. 2000), and to provide amenity functions such as surfing (Rendle and Rodwell 2014), diving (Wilhelmsson et al. 1998) and sea angling (Wilson 1991). Their success, however, has been variable (Baine 2001, Dafforn et al. 2015). There are many similarities between artificial structures designed for habitat and amenity, and those designed for coastal defence, suggesting that multi-functional coastal defence structures should be viable (Challinor and Hall 2008). Indeed several of these habitat and amenity services have been reported to arise incidentally as secondary functions from traditional coastal defence structures (e.g. Collins et al. 1994, Pister 2009). It has been argued, however, that unless designed with specific objectives in mind (e.g. target species), net ecological benefits are unlikely to be truly realised (Pickering and Whitmarsh 1997, Challinor and Hall 2008, Sella and Perkol-Finkel 2015), and recreational uses are unlikely to be compatible (e.g. Airoldi et al. 2005). Nevertheless, artificial surfing reefs are increasingly being adopted for coastal protection (Lokesha et al. 2013) and there is an expanding body of evidence to support the potential for ecologically-beneficial designs to be incorporated into coastal defence structures (Moschella et al. 2005, Chapman and Blockley 2009, Firth et al. 2013a, 2014, Perkol-Finkel and Sella 2014, 2016, Browne and Chapman 2014, Sella and Perkol-Finkel 2015, Evans et al. 2016).

Despite this known potential and policy recommendation, there remain numerous impediments to implementation of multi-functional coastal defence developments – perhaps as a function of the wider issue of ineffectual science-policy linkages (McNie 2007, Holmes and Clark 2008, Weichselgartner and Kasperson 2010). Further research is necessary to expand the knowledge base of alternative options, clarify choices and ultimately enable policy-makers to achieve desired outcomes (McNie 2007). To ensure research efforts and resources are invested effectively, it is first necessary to determine what secondary benefits can potentially be built-in to engineered coastal developments, and further, which of these benefits would be most desirable. It is unlikely that secondary benefits will be perceived in the same way across different stakeholder groups (e.g. conservation groups, engineers, statutory bodies and researchers; Naylor et al. 2012; see also Zanuttigh et al. 2015). Further, their order of priority when evaluating different design options is unlikely to be consistent, since each option will probably present a suite of compromises and trade-offs. For example, the addition of pits, crevices and rock pools to intertidal artificial structures may be an effective way of increasing biodiversity (Chapman and Blockley 2009, Firth et al. 2014, Browne and Chapman 2014, Evans et al. 2016) and stocks of exploited species (Martins et al. 2010), but they may not support the same assemblages as found in natural systems (Evans et al. 2016). Similarly, pre-cast concrete habitat enhancement units can be cheaply and easily deployed into structures (e.g. see BIOBLOCK demonstration project in Firth et al. 2014), but the net environmental benefits of enhancement using concrete, with its associated large carbon footprint (Flower and Sanjayan 2007), may be reduced (Perkol-Finkel and Sella 2014). Species of conservation interest can be transplanted onto structures (Clark and Edwards 1994, Perkol-Finkel et al. 2012, Ng et al. 2015, Ferrario et al. 2016), but this may have implications for local authorities tasked with maintaining those structures (Airoldi and Bulleri 2011). And reefs that aggregate commercial fish species may economically benefit professional and/or recreational fisheries (Collins et al. 1994), but they may lead to over-exploitation of populations if structures attract individuals from surrounding natural habitats rather than produce additional biomass (Pickering and Whitmarsh 1997). Habitat interventions may be designed with specific ecological and socio-economic responses in mind, but planners are required to judge the relative merits of each response in order to select the optimal design.

The aim of this study was to investigate stakeholder attitudes towards multi-functional coastal defence developments across different sector groups. A perception study was carried out in England and Wales using a traditional quantitative questionnaire and a semi-quantitative modified Delphi survey (Dalkey 1969, Mukherjee et al. 2015). Stakeholders in England and Wales were targeted, specifically, because of the scale of the challenges regarding coastal flooding and erosion (i.e. almost 40% of the coastline of England and Wales is already under some form of coastal protection: Masselink and Russell 2013). The questionnaire was designed to gather preliminary information about perceptions of coastal defences and the potential to incorporate secondary benefits into developments (Evans 2016). A modified Delphi technique was then employed to elicit detailed information and professional judgements from a panel of experts and practitioners from seven different sectors. The objectives were to: (i) determine the most important considerations for planning coastal defence developments and their perceived order of priority; (ii) determine the potential secondary benefits that can be built-in to coastal defence developments and their perceived order of priority; (iii) determine the level of support for implementing multi-functional coastal defences; and (iv) identify differences and consensus in perceptions across different sector groups. In light of comments received in the early stages of the Delphi study, a fifth objective was added, to: (v) identify the current barriers to effective implementation and steps for moving forward. This paper synthesises the findings of this study and proposes a four-step process to implementation of multi-functional coastal defence developments that can deliver secondary ecological and/or socio-economic benefits, as recommended by environmental legislation. Although here the focus is on coastal defence structures, the philosophy and findings of this research may be equally relevant for the planning and design of any other developments in the marine environment (e.g. for oil and gas exploration, renewable energy generation, navigation, mariculture, recreation) with the potential to support biodiversity and natural capital.

2. Materials and Methods

2.1 Survey instruments

A preliminary questionnaire survey was undertaken between March 2013 and September 2014 to gather scoping information about stakeholder perceptions of coastal defences and their potential to deliver secondary benefits. Questionnaires were distributed to stakeholders (SOM Table 1) and members of the public in England and Wales, and feedback was received from 118 respondents. Only one key finding from the questionnaire is presented in this paper but full details can be found in Evans (2016). Respondents were asked to indicate their level of support for traditional and then multi-functional coastal defence structures on a ten-point forced-choice (i.e. no neutral option) visual Likert scale (Allen and Seaman 2007), between ‘Not supportive at all’ and ‘Very supportive’. Responses were anonymised and coded to appropriate sector groups for analysis.

Based on insight gained from questionnaire responses (Evans 2016), a Delphi survey was devised to elicit detailed information and expert judgements regarding the desirability of secondary benefits that can be built-in to multi-functional coastal defence developments. The method is an effective yet underused and undervalued technique (Mukherjee et al. 2015) that provides an interactive communication structure between the researchers and a panel of experts with a vested interest in the problem at hand. Questions are asked over a number of rounds, and between each round, responses are analysed and fed back to the panel in an iterative process. This approach allows respondents to carefully consider and develop their answers over an extended period, in the context of rationale provided by other panel members (Garrod and Fyall 2000, 2005). Discrepancies and consensus may be identified (although consensus is not explicitly sought and will not be achieved if none exists), and information can be synthesised on highly complex and subjective problems that are not easily addressed using conventional questionnaires (Mukherjee et al. 2015).

In this study the panel consisted of 16 experts and practitioners from seven different sector groups across England and Wales (Table 1). Sector groups were defined based on responses received during the preliminary questionnaire survey. To ensure the expertise and perspectives of panel members were relevant to the subject of research, the Local Authority panellists were invited from coastal local authorities and the Statutory Bodies panellists were invited from teams with a marine/coastal remit. Similarly, panel members from the Conservation, Ecological and Engineering Consultant sectors all had experience in marine and coastal issues, and the Academic Non-specialists were both marine scientists. Academic Non-specialists were included in the study since they were anticipated to contribute an objective, critical and scientifically-literate perspective to the discussion.

Table 1 Number of Delphi panel members from each sector group.

Sector	Number of respondents
Academic Non-specialist (ANS)	2
Academic Specialist (AS)	1
Conservation (C)	2
Ecological Consultant (EcC)	2
Engineering Consultant (EnC)	2
Local Authority (LA)	2
Statutory Bodies* (SB)	5
N	**16**

*Statutory Bodies – Coastal Management and Nature Conservation

The size of the panel is not a critical feature of the Delphi technique (Smith 1995), but ‘balance’ in the panel, in terms of interests and expertise, is important throughout the process (Wheeller et al. 1990, Garrod 2012). There is an accepted element of judgement regarding what constitutes a balanced panel (Wheeller et al. 1990, Garrod 2012). In this study, a higher number of panel members was included from the Statutory Bodies sector due to the diversity of organisations and remits within that sector, and the applied nature of the issues being addressed.

Panel members were asked to commit to three survey rounds: one scoping round and two convergence rounds (Green et al. 1990, Miller 2001), which were conducted over a period of three months between September and December 2014. Between each round, responses were analysed and summarised in synthesis reports which were returned to the panel for consideration along with the next round of questions. The study was conducted via email, retaining anonymity throughout. The aim of this was to avoid the risk of bias in responses caused by the influence of personality or institutional allegiances (Frechtling 1996). Panel members were asked to respond fully and thoughtfully and to provide rationale where appropriate.

2.2 Progression through preliminary rounds

Results presented in this paper reflect final outcomes from a modified Delphi study, following three rounds of questions. It was considered a 'modified' Delphi study since the wording of questions and ranked lists evolved between rounds in response to feedback from the panel. This precluded systematic assessment of consensus development as per a traditional Delphi study (e.g. Garrod and Fyall 2000), but as a result, final outcomes were agreed (by the panel) to be more meaningful and valuable for informing marine management policy and practice. To place the findings in the appropriate context, it is necessary to comment on how the process developed through preliminary rounds. The response rate was 100% in all three rounds of the survey.

Round 1 (the scoping round) consisted of three open-ended questions designed to gather full and detailed information on the subject of research (Box 1).

Box 1. Three overarching questions answered by the Delphi survey panel in Round 1

Q1. What are the most important considerations when planning coastal defence works (i.e. construction or maintenance of engineered coastal defence structures)?

Q2. What are the potential secondary benefits of engineered coastal defence structures (i.e. beyond their primary function of providing protection against flooding and erosion)?

Q3. Would you be more supportive of the construction of additional coastal defences around the UK if they were multi-functional structures (i.e. ones that deliver secondary ecological and/or socio-economic benefits)? Why?

Several major themes emerged in the responses provided to Round 1 Questions 1 and 2 (Box 1), which were organised into subthemes and synthesised into two lists of 20 considerations (*cf* Box 1, Question 1) and 20 potential secondary benefits (*cf* Box 1, Question 2) which were presented back to the panel (SOM Tables 2 and 3). In Round 2 the panel was asked to rank both lists on a priority scale between one and 20 (1 = 'High priority', 20 = 'Low priority'). Several panel members commented on the difficulty of ranking a list of 20 options on one linear scale of priority and offered suggestions for reducing the lists. In response, for Question 1 (Box 1) the initial list of 20 considerations was reduced down to a new list of ten implementation-level considerations which the panel was asked to rank in Round 3 (1 = 'High priority', 10 = 'Low priority'; results presented in *3.1*). As part of this reduction process, considerations framed as opposite *positive* and *negative* impacts were combined into single considerations framed as *net* impacts. To account for this forfeit of detail regarding the relative importance of positive and negative impacts, a summary statement was constructed (Box 2), with which panel members were asked to indicate their level of agreement in Round 3, on a standard five-point Likert scale (1 = 'Strongly disagree', 2 = 'Disagree', 3 = 'Neither agree nor disagree', 4 = 'Agree', 5 = 'Strongly agree'; results presented in *3.1*).

Box 2. Summary Statement 1

"Considerations for avoiding/minimising negative impacts are more important than considerations for creating/maximising positive impacts."

For Question 2 (Box 1), the initial list of 20 potential secondary benefits was split into two new lists of 15 implementation-level secondary benefits (i.e. features that could actively be built-in to hard coastal defence structures) and ten potential reasons for building them in. The panel was again asked to rank these lists in order of priority in Round 3 (1 = 'High priority', 15/10 = 'Low priority'; results presented in *3.3*).

Scoping round responses to Question 3 (Box 1) were used to construct six summary statements to reflect the range of opinions expressed, along with alternative opinions created for the purpose of the study. In Round 2 the panel was asked to select the statement with which they agreed most (results presented in *3.2*). To investigate the potential for consensus on this issue, in Round 3 a new summary statement was constructed which combined elements of the most favoured statements from Round 2. Panel members were again asked to indicate their level of agreement with this statement on a standard five-point Likert scale (results presented in *3.2*).

In Round 1, the panel provided valuable comments regarding perceived barriers to effective implementation and suggestions for moving forward. Although the survey did not explicitly seek comment on these themes, this was considered valuable information and additional questions were included in subsequent rounds to gather more complete perceptions. Several additions were put forward in Round 2, from which two lists of ten current barriers and ten suggestions for moving forward were constructed to take forward to Round 3. The panel was once again asked to rank these lists in order of priority (1 = 'High priority', 15/10 = 'Low priority'; results presented in *3.4*).

In response to concerns raised in previous rounds, in Round 3 the panel was explicitly asked to consider potential secondary benefits "*as beneficial features of a hard defence structure evaluated against the same hard defence structure without the added beneficial features*" (i.e. not against alternative coastal management strategies). They were also asked to assume that "*the secondary benefits can be built-in to structures with no compromise of primary function or additional negative impacts, and that they can achieve their intended purpose*".

2.3 Data analysis

Visual Likert scale responses collected via the preliminary questionnaire were converted to scores between one and ten (1 = low, 10 = high), assuming even spacing between the ten-point scale intervals (Allen and Seaman 2007). A Wilcoxon Signed Ranks test was used to test for differences between overall median levels of support for traditional and multi-functional coastal defence structures. This non-parametric test was used because of non-normality in scores. One-way analysis of variance

(ANOVA) was used to test for differences in the mean levels of support for traditional and multifunctional structures, and the *difference* in levels of support for each, between sector groups. Student-Newman-Keuls post-hoc tests were used to identify pairwise significant differences. Analyses were carried out in SPSS (IBM Corp. Version 21, 2012).

In the Delphi study, scoping round (Round 1) responses were coded using NVivo qualitative data analysis software (QSR International Pty Ltd. Version 10, 2014) and organised into overarching themes and subthemes for each question. Themes and subthemes were then translated into lists of options for ranking in subsequent rounds.

In convergence rounds (Rounds 2 and 3), individual ranks assigned by panel members were converted to scores on an inverted scale between one and the number of options available for ranking n (1 = low, n = high). Scores were summed over responses from the whole panel, and also over responses provided by panel members from each of the seven sectors separately. Total scores were then converted back into overall priority rankings between one and n (1 = 'High priority', n = 'Low priority'). Box and whisker plots of median scores, interquartile ranges and outliers (i.e. ranks lying outside 1.5 times the interquartile range) were plotted to visually assess the level of consensus among the panel. Hierarchical cluster analysis (using group average linkage of Euclidean similarity matrices) was applied to mean scores, averaged over sectors, and dendrograms were plotted to coarsely illustrate agreement and disagreement between sector groups (SOM Figure 1).

3. Results

Questionnaire responses collectively indicated significantly increased levels of support for additional coastal defence structures in the UK *if they were multi-functional structures* (Wilcoxon Z = -7.377, $P < 0.001$) (Figure 1). The magnitude of increase was consistent across all sectors ($F_{7,117} = 1.250$, $P = 0.282$). Respondents from the Statutory Bodies sector indicated the lowest mean levels of support for both standard (4.1 ± 0.6 SE) and multi-functional structures (5.8 ± 0.7 SE), whilst respondents from the Engineering Consultant sector indicated the highest levels of support (7.7 ± 0.8 SE and 9.0 ± 0.5 SE, respectively). The difference in support for additional (non multi-functional) coastal defence structures between these two sectors was significant ($F_{7,117} = 2.578$, $P = 0.017$; SNK $P < 0.05$). No other significant differences were found.

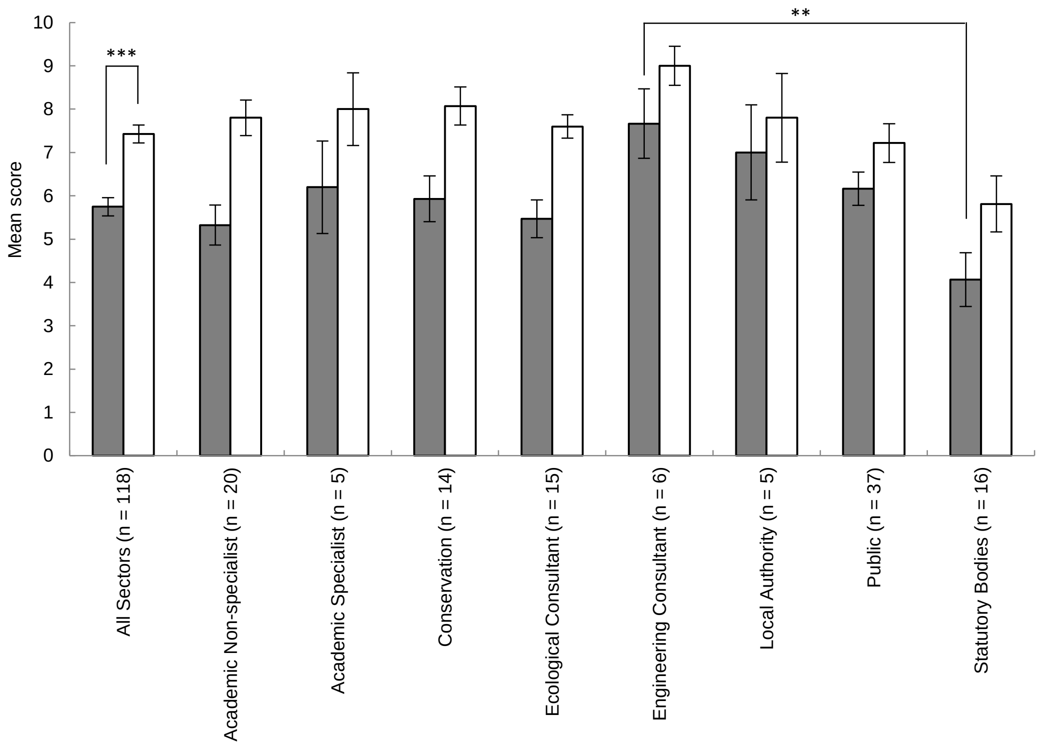

Figure 1 Level of support for additional coastal defence structures (grey bars) and additional multi-functional coastal defence structures (white bars), as indicated by mean scores (± SE; n = 118) assigned by questionnaire respondents on a scale of 1 to 10 (1 = 'Not supportive at all', 10 = 'Very supportive'). Significant differences are indicated (**: p < 0.05, ***: p < 0.001).

3.1 Most important considerations when planning coastal defence developments

In the Delphi study Round 3 Question 1, the panel was asked to rank ten considerations for planning coastal defence works: firstly based on the *current* order of priority in practice (Table 2, 'Panel[1]'), and secondly based on what they thought the order of priority *should* be (Table 2, 'Panel[2]'). Panellists were given the option of not completing the ranking for the former (Panel[1]) if they felt unqualified to do so. Twelve panel members provided answers, four of whom indicated that they felt somewhat unqualified but had provided their best-informed guess. The overall order of priority was the same regardless of whether these data were included or excluded. Unsurprisingly, the panel ranked 'Essential criteria' as the most important consideration. They then ranked 'Cost', followed by 'Net socio-economic impacts on local communities and businesses', followed by 'Net ecological impacts' as the next highest current priorities in turn, but indicated that 'Net ecological impacts' *should* be considered more important than 'Net socio-economic impacts', and both *should* be considered more important than 'Cost'. At the bottom end of the scale, 'Carbon footprint', 'Opportunities for research and development' and 'Opportunities for education and outreach' were ranked as the lowest priorities currently. The panel indicated, however, that 'Carbon footprint' and 'Opportunities for research and development' *should* be given higher priority than 'Level of community support' and 'Net culture and heritage impacts'.

There was a relatively high degree of consensus for the panel's highest and lowest rankings of how considerations *should* be prioritised (Figure 2; see also SOM Figure 1a). However, there was very little consensus regarding the middle ranks such as 'Cost', 'Landscape impacts', 'Carbon footprint' and 'Community support'. Panel members from the Conservation sector and the Statutory Bodies sector perceived 'Cost' to be less important than those from other sectors (Table 2); in fact, panel members from the Conservation sector collectively ranked it as their lowest priority. Views expressed on 'Cost' varied widely, for example:

> "*I believe all of the considerations listed … to be of greater importance than the overall cost of the coastal defence works.*"
> (Statutory Bodies)

> "*In an ideal world the cost of defence structures would not be as important as their primary functionality … and their net ecological impacts.*"
> (Academic Non-specialist)

> "*[Cost] is still sort of fixed and I'm not sure you can rank it.*"
> (Local Authority)

> "*We are in very challenging financial times and the drivers around any capital spend have to be set against this background.*"
> (Statutory Bodies)

Panel members from the Conservation and Statutory Bodies sectors ranked 'Carbon footprint' higher than the rest of the panel, and the Conservation sector also ranked 'Opportunities for education and outreach' (lowest priority overall) higher than the rest of the panel. It was suggested that:

"*We can only change perception of FCERM [Flood and Coastal Erosion Risk Management] if education is built in better to schemes.*"
(Statutory Bodies)

To investigate the relative importance of associated positive and negative impacts on ecology and local communities (in the context of planning coastal defence developments), a summary statement was constructed, with which panel members were asked to indicate their level of agreement (Box 2).

Fifteen out of 16 panel members indicated that they 'Agree' or 'Strongly Agree' that considerations for avoiding/minimising negative impacts are more important than considerations for creating/maximising positive impacts. Some panel members raised concern, however, regarding the generality of the statement. For example:

"*Certainly for ecology and coastal processes – not sure if this necessarily applies to businesses.*"
(Local Authority)

One panellist from the Statutory Bodies sector indicated that they 'Strongly Disagree' with the statement, commenting that:

"*Any new structure will have a negative impact, just avoiding/minimising is not really good enough, the aim should be to do something better.*"
(Statutory Bodies)

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Table 2 Considerations for planning coastal defence works in order of priority, as indicated by combined rankings of the Delphi panel (Panel[1] = perceived *current* order of priority, Panel[2] = *preferred* order of priority) and by combined rankings (*preferred* order of priority) of panel members from different sectors (1 = high, 10 = low).

CONSIDERATIONS	Panel[1]	Panel[2]	ANS	AS	C	EcC	EnC	LA	SB
Essential criteria (i.e. part of a sustainable strategy, justification, in line with environmental legislation and planning guidelines, public safety, fit-for-purpose, no unintentional alteration to coastal processes, affordable/funding available)	1	1	1	1	1=	1	1	1	1
Cost (i.e. assuming funding is available)	2	4	4	4	10	3	3=	2=	6
Net socio-economic impacts on local communities and businesses (i.e. assuming minimum requirements are met and not including risk reduction from primary defence function: e.g. reduced/enhanced amenity, recreation, fisheries, navigation, tourism, employment, etc.)	3	3	3	3	5	4	3=	2=	3
Net ecological impacts (i.e. assuming minimum requirements are met and not including risk reduction from primary defence function: e.g. loss/disturbance of habitats/species, dispersal of invasive non-native species, extraction of raw materials, novel habitat/refuge for exploited species or species of conservation interest, etc.)	4	2	2	2	1=	2	2	2=	2
Net landscape impacts (i.e. assuming minimum requirements are met)	5	5	5=	6	6=	5	5	5=	5
Level of community support (i.e. assuming minimum requirements are met)	6	8	7	5	6=	6=	6	7	9
Net culture and heritage impacts (i.e. assuming minimum requirements are met and not including risk reduction from primary defence function: e.g. loss/damage of heritage features or archaeology, platform for art installations, etc.)	7	9	9	7	6=	8	7=	5=	8
Carbon footprint (i.e. assuming minimum requirements are met: e.g. processing and transport of raw materials, construction emissions, etc.)	8	6	8	8	3	9	7=	9	4
Opportunities for research and development (e.g. new engineering designs, experimental units to investigate marine/coastal ecology)	9	7	5=	10	4	6=	7=	8	7
Opportunities for education and outreach (e.g. platform for environmental education, etc.)	10	10	10	9	6=	10	10	10	10

ANS: Academic Non-specialist; AS: Academic Specialist; C: Conservation; EcC: Ecological Consultant; EnC: Engineering Consultant; LA: Local Authority; SB: Statutory Bodies

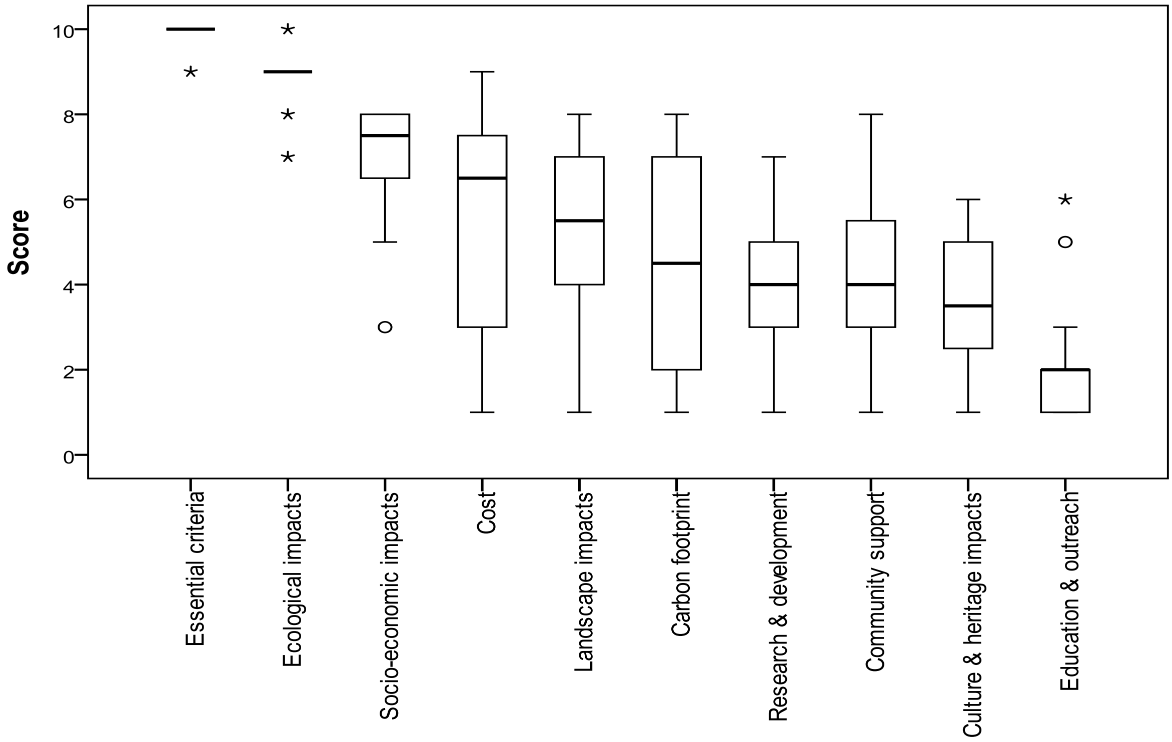

Figure 2 Median scores (inverted ranks in *preferred* order of priority, i.e. 10 = high, 1 = low) assigned to considerations for planning coastal defence works by the Delphi panel, with interquartile ranges (box), maximum/minimum scores (whiskers), outliers > 1.5 x interquartile range (○) and extreme outliers > 3 x interquartile range (⋆).

3.2 Level of support for implementing multi-functional coastal defence structures

To assess the level of stakeholder support for the concept of multi-functional coastal defence developments, in Round 2 Question 3 the panel was asked to indicate with which of six summary statements they agreed most (Figure 3). Largely, opinion was divided between Statements 5 and 4, reflecting caveated support for multi-functional structures, and Statement 2, reflecting more general support for multi-functional structures *if* new structures are deemed necessary. One panel member from the Statutory Bodies sector selected Statement 1, reflecting lack of support for hard structures regardless of multi-functionality, citing concerns about unsustainable long-term coastal management. In contrast, several panel members expressed disagreement with this statement (and with Statements 6 and 2), suggesting that in certain scenarios hard defences are necessary and part of the strategic approach to flood and coastal erosion risk management. Several panel members indicated that their opinions would

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be better-represented by a combination of two or more statements. In particular, Statement 4 was frequently referred to as a second choice by those who selected Statement 5, and vice versa.

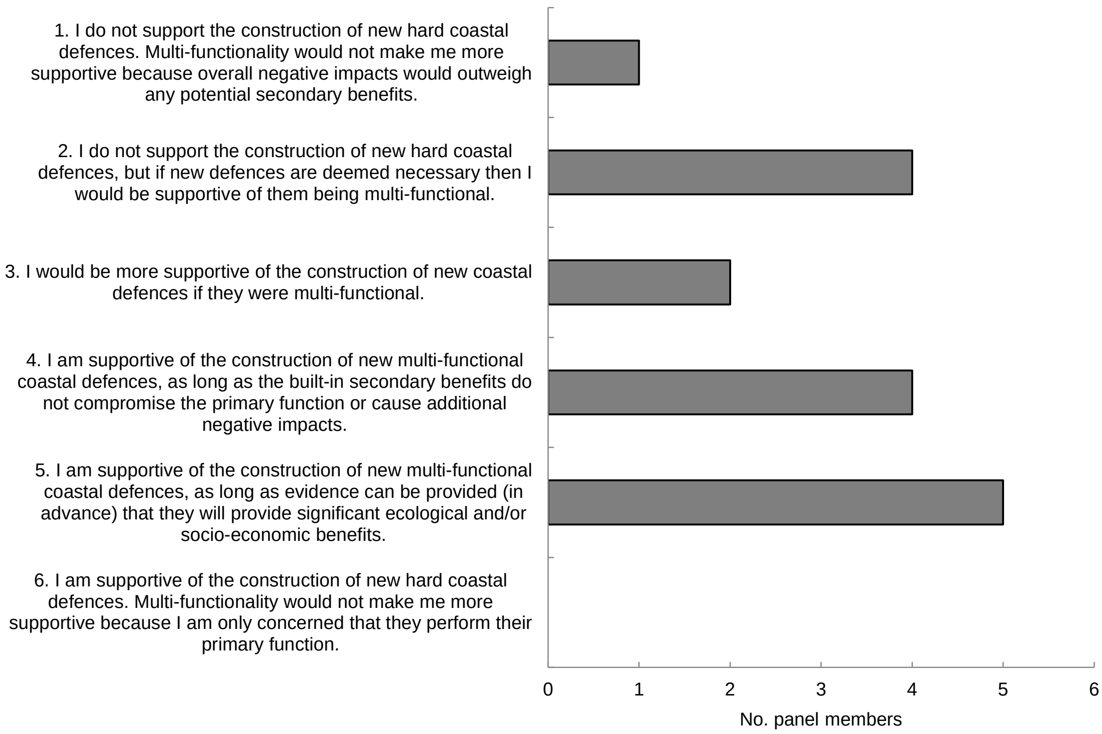

Figure 3 Frequency of selection for each of six summary statements by the Delphi panel. Panel members were asked to select the statement with which they agreed most.

Moving forward to Round 3, a new summary statement was constructed, that combined elements of the most favoured statements from Round 2, and did not include any reference to support or non-support of hard coastal defences in general (Box 3). Fifteen out of 16 panel members indicated that they ‘Agree’ or ‘Strongly Agree’ that they would be more supportive of hard coastal defence structures (where deemed necessary) being multi-functional structures, as long as the two caveats in Summary Statement 2 (Box 3) were satisfied.

Box 3. Summary Statement 2

"Where hard coastal defence structures are deemed necessary, I would be more supportive of them being multi-functional structures, as long as built-in secondary benefits do not compromise primary defence function or cause additional negative impacts, and evidence can be provided that intended ecological and/or socio-economic benefits will be realised."

One panel member from the Engineering Consultant sector selected 'Neither Agree nor Disagree', commenting that:

> "*It is important to demonstrate that there is a benefit from an engineering perspective too, some positive feedback that makes the structure perform better*."
> (Engineering Consultant)

Two panel members also felt that the statement should specify that:

> "*The secondary benefits should be of a reasonable cost.*"
> (Local Authority)

and that any additional cost would need to be:

> "*in proportion to the effect/evidence.*"
> (Statutory Bodies)

Conversely, three panellists (from the Conservation, Academic Non-specialist and Statutory Bodies sectors) felt that the statement was too constrained by the need to provide evidence, which may be an unreasonable obstacle to implementation. It was suggested that:

> "*There will always be a level of uncertainty … [but] this should not be a reason NOT to design structures with secondary aims in mind.*"
> (Academic Non-Specialist)

Instead, based on existing evidence from other areas:

> "*There should be a presumption that there will be some positive effect.*"
> (Statutory Bodies)

3.3 Potential secondary benefits that can be built-in to coastal defence structures (and motivations for building them in)

In Round 3 Question 2 the panel ranked 'Habitat for natural rocky shore communities', 'Habitat for species of conservation interest' and 'Refuge for exploited species' as the highest priority secondary benefits that could be built-in to multi-functional coastal defence structures (Table 3, 'Panel'). At the bottom end of the scale, the panel perceived 'Opportunities for education and outreach', 'Enhanced landscape value' and 'Enhanced culture and heritage value' as the lowest priorities. Accordingly, the panel indicated that 'Positive ecological impacts', 'Divert pressure from natural systems' and 'Positive socio-economic impacts on local communities and businesses' were the primary motivations for implementing multi-functional designs in coastal defence developments. 'Culture and heritage', 'Education and outreach' and 'Reduce carbon footprint' were of least concern (Table 4, 'Panel').

There was a reasonable level of consensus in what the panel ranked as the highest and lowest secondary benefits (Figure 4a; see also SOM Figure 1b) and reasons for building them into developments (Figure 4b; see also SOM Figure 1c). There was little agreement regarding the middle ranks. With regard to secondary benefits (Table 3), the Academic Specialist assigned their top ranks differently to the rest of the panel, prioritising socio-economic and technical benefits (i.e. 'Enhanced amenity/recreation', 'House other technologies' and 'Enhanced commercial fisheries') above the more direct ecological benefits. They suggested that if socio-economic secondary benefits are prioritised, then ecological ones can still be built-in around them.

Panel members from the Local Authority and Engineering Consultant sectors also ranked 'Enhanced amenity/recreation' high, whereas those from the Conservation and Statutory Bodies sectors ranked this particularly low. Panel members from the Conservation sector instead favoured 'Safeguarded biosecurity', as did the Academic Specialist and Ecological Consultants, whereas the Engineering

Consultants ranked this as their lowest priority. The Engineering Consultants also ranked ‘Refuge for exploited species’ lower than the rest of the panel, but instead prioritised ‘Reduced carbon footprint’ and ‘Enhanced landscape value’. Finally, panel members from the Academic Non-specialist and Statutory Bodies sectors ranked ‘Mariculture opportunities’ higher than the panel as a whole. Some considered this as an opportunity for co-location of marine activities, akin to ‘House other technologies’, and ranked it high:

> “*given the increasingly busy state of the seas.*”
> (Statutory Bodies)

Others, however, were sceptical of the viability of this secondary benefit:

> “*due to differences in the scale of the operation and the optimal location for such activities.*”
> (Academic Non-Specialist)

and raised concern about:

> “*introductions of species novel to the system.*”
> (Ecological Consultant)

This latter concern was shared by several panel members in relation to some of the highest ranking ecological benefits, i.e. ‘Habitat for natural rocky shore communities’, ‘Habitat for species of conservation interest’ and ‘Habitat heterogeneity in structure design’. The importance of site-specific decision-making was a clear message from the panel throughout the process – any potential ecological benefits must be evaluated in the context of local natural habitats.

When ranking reasons for building-in benefits (Table 4), panel members from the Engineering Consultant and Local Authority sectors assigned their highest priority differently to the rest of the panel, prioritising ‘Reduce maintenance requirements’ and ‘Increase likelihood of scheme progression’, respectively. Panellists from both of these sectors nevertheless ranked ‘Positive ecological impacts’ and ‘Positive socio-economic impacts’ joint second, indicating agreement with the overall panel perception that these are primary motivations for building-in secondary benefits. In contrast, panel members from

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the Conservation and Ecological Consultant sectors assigned particularly low priority to 'Increase likelihood of scheme progression'. One panel member commented that:

> "*If a defence structure is being planned it is a necessity in whatever form decided upon … therefore, I believe it is not a case that it will progress any faster/smoother as a result of added enhancements.*"
>
> (Ecological Consultant)

Panellists from the Conservation sector also ranked 'Positive socio-economic impacts' much lower than the rest of the panel. Instead they prioritised 'Reduce carbon footprint', 'Research and development' and 'Education and Outreach'. Academic Non-specialists and Ecological Consultants also ranked 'Research and development' higher than the rest of the panel, whereas the Academic Specialist again ranked this low. There was little agreement in ranks assigned to 'Enhance/safeguard landscape': although panel members from the Academic Non-specialist, Ecological Consultant and Statutory Bodies sectors ranked it fairly highly, it was lowest priority for the Academic Specialist as they felt it was not a tangible secondary benefit. Also at the bottom of the rankings, 'Culture and heritage' and 'Education and outreach' were consistently perceived as low priority considerations for secondary benefits. Rationale for this was provided by some panel members, including that there are more appropriate places to cater for these activities, and also that it is difficult to value them and identify a beneficiary through which to balance associated costs.

Table 3 Potential secondary benefits that can be built-in to multi-functional coastal defence structures in order of priority, as indicated by combined rankings of the Delphi panel and by combined rankings of panel members from different sectors (1 = high, 15 = low).

SECONDARY BENEFITS	Panel	ANS	AS	C	EcC	EnC	LA	SB
Habitat for natural rocky shore communities (e.g. build-in microhabitat complexity and use materials suitable for natural rocky shore communities)	1	2	9	4	1	1=	5	1
Habitat for species of conservation interest (e.g. build-in habitat suitable for wintering birds, BAP species, etc.)	2	4=	5	1=	5	1=	2	3
Refuge for exploited species (e.g. build-in refuge habitat suitable for exploited species to allow populations to persist)	3	4=	7	1=	2=	9=	6	2
Habitat heterogeneity in structure design (e.g. build-in mosaic of habitats such as rocky substrate, sediments, saltmarsh patches, etc.)	4	1	6	5	2=	4	3=	5
Enhanced commercial fisheries (e.g. build-in refuge/nursery habitat for commercial species)	5	3	3	7	6=	5=	3=	8
Safeguarded biosecurity (e.g. build-in features to remove/reduce competitive advantage of non-native invasive species)	6	8=	4	3	4	15	7	7
Enhanced amenity/recreation (e.g. build-in surf reef design, promenade, beach access, recreational fishing platform, etc.)	7=	10	1	13	8=	3	1	12
House other technologies (e.g. build-in turbines, masts, etc.)	7=	11	2	8=	6=	9=	8	6
Mariculture opportunities (e.g. build-in facilities for mussel/macroalgae culture)	9	4=	8	10	13	13=	9	4
Reduced carbon footprint (e.g. use novel low-carbon materials or recycled waste materials)	10	12	11	8=	11=	5=	14	9
Opportunities for research and development – new engineering solutions (e.g. trial novel materials and structural designs)	11	7	10	11=	11=	8	10	13=
Opportunities for research and development – investigating marine/coastal ecology (e.g. build-in experimental mesocosm units)	12	8=	14	6	10	11	11=	13=
Enhanced landscape value (e.g. use natural materials, subtle design or aesthetically-attractive design)	13	13	15	14	8=	5=	11=	10
Opportunities for education and outreach (e.g. build-in facilities for public engagement or environmental education)	14	14=	13	11=	14	13=	15	11
Enhanced culture and heritage value (e.g. build-in art installations)	15	14=	12	15	15	12	13	15

ANS: Academic Non-specialist; AS: Academic Specialist; C: Conservation; EcC: Ecological Consultant; EnC: Engineering Consultant; LA: Local Authority; SB: Statutory Bodies

Table 4 Potential reasons for building-in secondary benefits to coastal defence structures in order of priority, as indicated by combined rankings of the Delphi panel and by combined rankings of panel members from different sectors (1 = high, 10 = low).

REASONS FOR BUILDING-IN SECONDARY BENEFITS	Panel	ANS	AS	C	EcC	EnC	LA	SB
Positive ecological impacts (i.e. through enhanced connectivity/resilience of rocky habitats, habitat for exploited species, habitat for species of conservation concern, habitat heterogeneity, etc.)	1	1	3	1	1	2=	2=	1
Divert pressure from natural systems (i.e. by providing access for recreation, fisheries, research, co-location with other technologies etc.)	2	2=	1	2=	2	5	4	4
Positive socio-economic impacts on local communities and businesses (i.e. through enhanced amenity, recreation, fisheries, navigation, tourism, employment, etc.)	3	2=	2	8	3	2=	2=	2=
Increase likelihood of scheme progression (i.e. by fostering public support and improving partnership funding potential)	4	4=	5	7	9	4	1	5
Reduce maintenance requirements (i.e. by building-in positive feedback in stability of structure)	5	7	4	6	6=	1	5	8
Research and development (i.e. gather evidence necessary for moving forward with multi-functional coastal defences by trialling novel engineering designs and improving knowledge of marine/coastal ecology)	6	4=	9	4	4	6=	6	6
Enhance/safeguard landscape (i.e. by using natural materials, subtle design or aesthetically-attractive design)	7	4=	10	9	5	6=	7=	2=
Reduce carbon footprint (i.e. by using low carbon technology, recycled materials, etc.)	8	9=	6	2=	6=	8	9	7
Education and outreach (i.e. by building-in facilities for public engagement and environmental education)	9	9=	8	5	8	10	10	9
Culture and heritage (i.e. by building-in art installations, etc.)	10	8	7	10	10	9	7=	10

ANS: Academic Non-specialist; AS: Academic Specialist; C: Conservation; EcC: Ecological Consultant; EnC: Engineering Consultant; LA: Local Authority; SB: Statutory Bodies

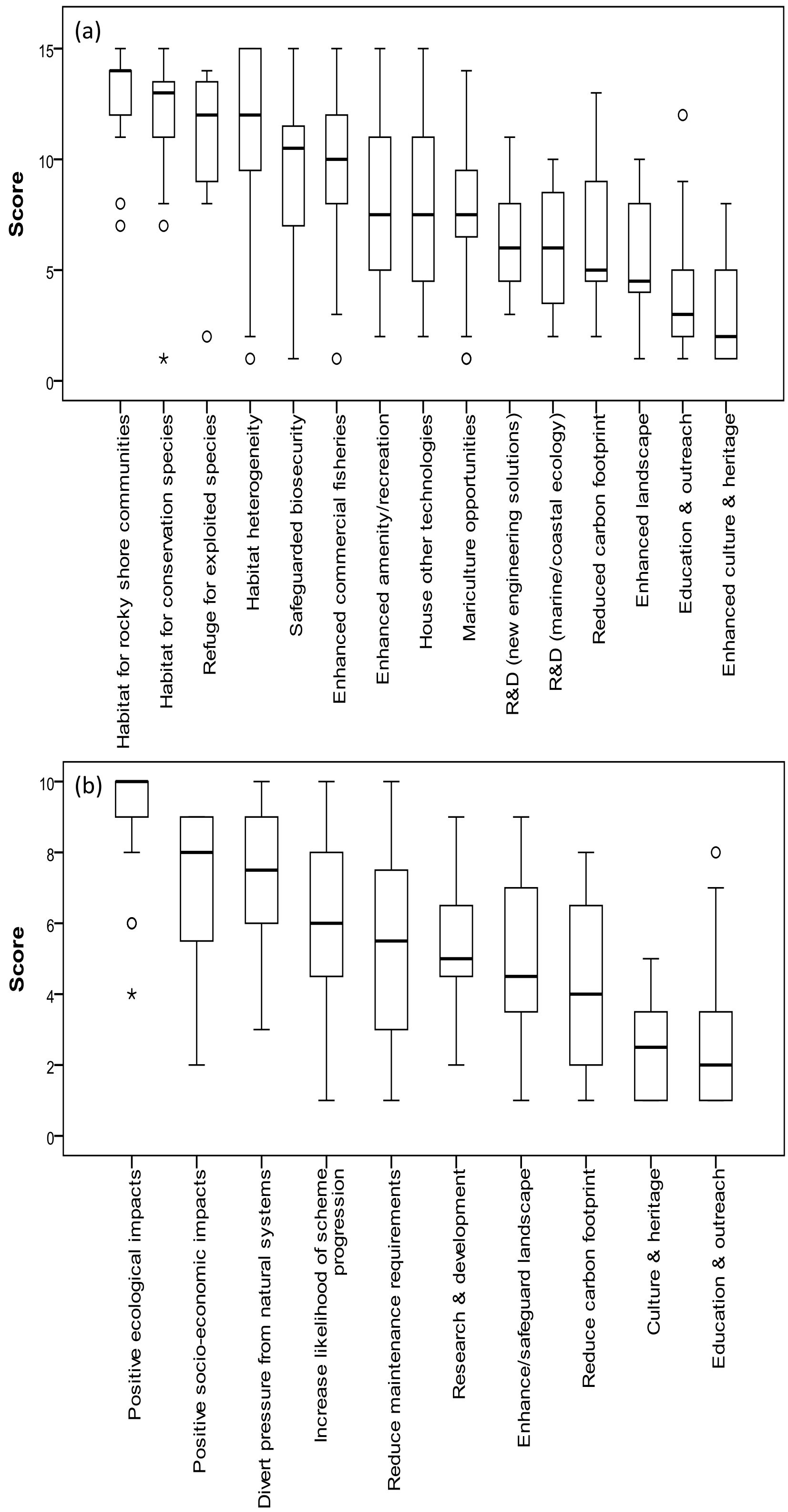

Figure 4 Median scores (inverted ranks, i.e. 15/10 = high, 1 = low) assigned to (a) potential secondary benefits and (b) reasons for building them into developments by the Delphi panel, with interquartile ranges (box), maximum/minimum scores (whiskers), outliers > 1.5 x interquartile range (○) and extreme outliers > 3 x interquartile range (⋆).

3.4 Current barriers to effective implementation of multi-functional coastal defences

In Round 3 Question 3 the panel was asked to rank ten current barriers to effective implementation of multi-functional coastal defence structures and ten suggestions for moving forward, in order of priority (Table 5). Several panel members commented, however, that all of the barriers and suggestions were pertinent, and little consensus was apparent in the rankings (SOM Figure 2). Others commented on the logical order in which barriers and suggestions for moving forward should be addressed. These comments were utilised to propose a four-step process to effective implementation of multi-functional coastal defence developments (Box 4), discussed further below.

Table 5 Current barriers to implementation and suggestions for moving forward with multi-functional coastal defence structures in order of priority, as indicated by combined rankings of the Delphi panel (1 = high, 10 = low).

CURRENT BARRIERS TO EFFECTIVE IMPLEMENTATION	**Panel**
Developments driven by cost and funding priorities	1
Lack of policy drive and legislative support	2
Ability to justify additional costs	3
Reliable assessment of value	4
Awareness of / engagement with the concept of multi-functionality	5
Lack of evidence that benefits will be realised	6
Poor communication between sectors during planning	7
Lack of well-understood ‘products’ (i.e. ecological engineering solutions)	8
Lack of understanding of ecology of manmade habitats	9
Lack of collaboration with EU/international partners (i.e. knowledge exchange)	10
SUGGESTIONS FOR MOVING FORWARD	**Panel**
Consider multi-functional designs in the planning stage of new defences	1
Strengthen legislative framework	2
Conduct cost-benefit analyses of potential secondary benefits	3
Conduct experimental trials to gather additional evidence	4
Make additional resources available to cover cost of multi-functional features	5
Improve awareness and engagement amongst relevant sectors	6
Develop ‘products’ that can be incorporated into scheme designs	7=
Develop new technologies to improve potential of multi-functional structures	7=
Expand beneficiary pays principal to include secondary benefits	9
Collaborate with EU/international partners (knowledge exchange)	10

4. Discussion

4.1 General consensus on priorities for coastal defence developments

Effective flood and coastal erosion risk management demands negotiation of many complex and conflicting stakeholder priorities. It is clear that stakeholders from different sectors have disparate personal and professional opinions on how coastal defence developments should be delivered. Nevertheless, the preliminary questionnaire survey indicated unanimous support for implementing multi-functional coastal defence structures in place of traditional single-purpose ones. The modified Delphi study revealed a more nuanced and caveated level of support, but further elicited some general consensus in terms of perceived highest and lowest priorities, despite the diverse panel composition with experts and practitioners from seven different sectors.

In general, the most important considerations for planning coastal defence developments (after ensuring essential criteria are met) were perceived to be their net ecological impacts and net socio-economic impacts on local communities and businesses. When asked about potential secondary benefits that could be built-in to developments, the Delphi panel favoured ecological benefits over social, economic and technical ones. Accordingly, primary motivations for incorporating secondary benefits were to deliver positive ecological and socio-economic impacts for the local environment and communities. There was, however, general agreement that it is more important to avoid or minimise negative impacts of developments than it is to create and maximise positive ones. This aligns with the mitigation hierarchy outlined in the EU Biodiversity Strategy (2011) "*No Net Loss Initiative*" and translated into national level policy (e.g. HM Government 2011): the first objective should be to avoid/prevent negative impacts; where this is impossible, damage should be minimised and restoration attempted; compensation or offsetting should be a last resort. Indeed it is important to note that secondary benefits that can be built-in to coastal defence developments, as discussed in this study, are not considered adequate mitigation or compensation for the loss of natural habitats and species caused by construction works. Building-in beneficial features should not, therefore, be prioritised over more sustainable flood and coastal erosion risk management approaches. However, where hard structures are considered necessary and appropriate for coastal management, then opportunities should be taken to maximise secondary benefits as well as minimising environmental impacts.

All of the considerations and potential secondary benefits evaluated in the Delphi study were put forward as being important by the panel. As such, none were considered unimportant or irrelevant. In general, however, the lowest priority considerations for coastal defence developments (and the secondary benefits that can be built-in to them) were perceived to be the provision of opportunities for education and outreach, and the net cultural and heritage impacts. Although it is widely accepted that direct experiences in nature can promote more environmentally-conscious behaviour (e.g. Kals et al. 1999), it was suggested that there are more appropriate opportunities for engaging the public with the marine environment. However, as one panellist commented, better education and outreach may be necessary to generate community support for more sustainable long-term management strategies. Community involvement in strategic planning has become commonplace in recent years (Ledoux et al. 2005) and in some cases, uninformed citizen-based decisions have led to inappropriate management strategies (Young et al. 2014, see also Layzer 2008).

It was pointed out that the absence of representation from the education, culture and heritage sectors on the panel may have biased the overall rankings against these options. This should be acknowledged as a limitation of the study. The panel was constructed so as to balance inclusion of a wide range of relevant sectors with the practicalities of processing responses within a reasonable time frame, and the likelihood of retaining 100% participation throughout the study.

4.2 Proposed steps to implementation of multi-functional coastal defences

As policy and legislation begins to recognise the need for developers to take a more pro-active role in protecting and enhancing the natural environment (e.g. HM Government 2011), this study provides some much-needed clarity on what can be done to deliver secondary ecological and socio-economic benefits from coastal defence developments. Based on findings from the modified Delphi study, this paper proposes a four-step approach to wide-scale and effective implementation of multi-functional coastal defence developments (Box 4), which will be useful to inform the future direction of research in this field.

Box 4. Steps to effective implementation of multi-functional coastal defences

Step 1: Gather evidence of efficacy of secondary benefits

Conduct a systematic evidence-gathering exercise, firstly collating existing evidence from the literature and via knowledge exchange with international partners, and secondly filling any knowledge gaps through experimental trials and targeted surveys.

Step 2: Value secondary benefits

Conduct cost-benefit analyses to make reliable valuations of the net benefits of different engineering options. It may be possible to identify beneficiaries of potential secondary benefits to attract additional partnership funding.

Step 3: Develop new technologies and ecological engineering "products"

Expand existing knowledge of ecological engineering solutions, from high-level design concepts and materials, to off-the-shelf habitat enhancement units tailored to support specific target species and services.

Step 4: Encourage implementation

Facilitate knowledge exchange and uptake to improve awareness and engagement amongst relevant sectors, and to encourage communication about multi-functional options during the planning stage of new developments.

It is important to note that the process need not start from the beginning of *Step 1* (gathering evidence; Box 4), nor be implemented in a linear order. A wealth of evidence already exists globally to support methods of enhancing artificial structures for environmental, social and economic benefit (see reviews by Baine 2001, Moschella et al. 2005, Chapman and Underwood 2011, Firth et al. 2014, 2016a, Dafforn et al. 2015). Nevertheless, a lack of evidence that secondary benefits can be realised, and a lack of understanding of the ecology of artificial habitats, were both perceived to be barriers to effective implementation by the Delphi panel. This led to the general consensus that they would be more supportive of multi-functional coastal defence structures *only if evidence can be provided* that the intended benefits will be realised (Box 3). It was pointed out, however, that this obligation to provide evidence may become an unreasonable obstacle to implementation and further experimentation. This echoes previous appeals in the literature (Bulleri and Chapman 2010, Chapman and Underwood 2011, Naylor et al. 2012, Sella and Perkol-Finkel 2015) where it has been argued that implementation, with experimental control and long-term monitoring, is necessary in order to gather further evidence. It will be necessary, therefore, for decision-makers to accept a degree of uncertainty in early practice, to strengthen the evidence base across different environmental contexts and enable greater confidence in decision-making in future.

Another key perceived barrier to implementation was the ability to justify additional costs that may be associated with multi-functionality. Throughout this study, there was considerable discrepancy in opinions regarding the importance of cost. Although financial constraints are often a substantive limitation of conservation efforts globally (McKinney 2002, Balmford et al. 2003, McCarthy et al. 2012), there is increasing recognition of the value of natural capital – the goods and services that can be supported by a healthy natural environment (Costanza et al. 2014). Numerous tools are available for assessing the value of these goods and services (e.g. Mitchell and Carson 1989, Hanley et al. 1998, Carr and Mendelsohn 2003) and the associated costs of protecting them (e.g. Marxan, Ball et al. 2009). But although socio-economic secondary benefits of coastal defence developments may be readily evaluated (e.g. enhanced commercial fishery), further research is necessary (*Step 2*; Box 4) to reliably assess the non-use value of (and justify additional costs of) potential *ecological* secondary benefits (e.g. provision of habitat for conservation species). The panel acknowledged the challenging financial climate in which flood and erosion risk management decisions are necessarily being made in the UK (Committee on Climate Change 2014), as in other parts of the world (Nicholls and Tol 2006, Hinkel et al. 2013), but also pointed out the potential to attract partnership funding (Defra 2011) from identified beneficiaries of potential secondary benefits. Again, potential sources of partnership funding may be more obvious for socio-economic secondary benefits than for ecological ones, but it was suggested in this study that the beneficiary could conceivably be UK PLC if none more specific could be identified. This implies that benefits to society in general could feasibly attract public funding (see Seattle Seawalls case study described in Naylor et al. 2012 for an example of this).

As stressed by the Delphi panel, any built-in secondary benefits must be designed and evaluated in the context of the local environment and communities in question. They must also be tailored to the requirements of the specific targeted species or services desired. Through further experimental trials, new technologies and products may be developed (*Step 3*; Box 4) to provide a catalogue of off-the-shelf ecological engineering solutions necessary to deliver the range of potential secondary benefits that have been identified (see *Future directions for research* in Bulleri and Chapman 2010). Since so many coastlines have already been artificially hardened globally (Koike 1996, Davis et al. 2002, Chapman and Bulleri 2003, Airoldi and Beck 2007, Firth et al. 2016a), it is important to seek engineering solutions that can be applied retrospectively to existing structures (e.g. Martins et al. 2010, Firth et al. 2014, Browne and Chapman 2014, Evans et al. 2016, Perkol-Finkel and Sella 2016) as well as to investigate multi-functional designs for new developments (e.g. Chapman and Blockley 2009, Jackson et al. 2012, Firth et al. 2014, Dafforn et al. 2015, Scyphers et al. 2015, Sella and Perkol-Finkel 2015, Perkol-Finkel and Sella 2014, 2016).

Some Delphi panel members commented that the legislative framework, communication between sectors and awareness of multi-functional structures all exist, despite these being perceived as barriers by others. They instead suggested that what is lacking is the robust evidence needed to drive policy changes and encourage engagement with the concept of multi-functionality. In reality, the greater barrier appears to be a lack of awareness of, or access to, the body of evidence that currently exists. It is unrealistic to expect practitioners across different sectors to keep abreast of the rapidly-expanding body of academic literature in this field (Holmes and Clark 2008). The ineffectiveness of the "loading-dock approach" – simply putting information out there and expecting it to be used as intended – has been commented on previously (Cash et al. 2006). Instead, it is necessary for researchers to pro-actively facilitate knowledge exchange and uptake through training sessions and practitioner-focused workshops. The role of 'interpreters' (Holmes and Clark 2008), 'boundary organisations' (Cash et al.

2006, McNie 2007) or 'knowledge brokers' (Naylor et al. 2012) has been championed in the science-policy literature. These individuals or organisations 'bridge the gap' between the producers and users of knowledge, to ensure research is more visible and useful to decision-makers (Cash et al. 2006, McNie 2007, Holmes and Clark 2008, Naylor et al. 2012). The independent not-for-profit body, CIRIA (the Construction Industry Research and Information Association, www.ciria.org), has emerged as an effective intermediary group in the field of ecological engineering and green infrastructure in the UK (but also operating internationally). If *Steps 1-3* (Box 4) can be achieved, and evidence can be effectively communicated to policy-makers and practitioners, then more specific policies may develop to strengthen the legislative framework in which secondary benefits are considered. This would provide the incentive and confidence required to encourage engagement and communication between sectors about multi-functional options during the planning stage of new developments (*Step 4*; Box 4).

4.3 Conclusions

In this study a stakeholder perception study was conducted, by applying a modified Delphi technique to elicit and untangle stakeholder opinions regarding: (i) the most important considerations for planning coastal defence developments; (ii) the potential secondary benefits that can be built-in to coastal defence structures; (iii) the level of support for multi-functional coastal structures; (iv) differences and consensus in perceptions across sector groups; and (iv) the steps necessary to achieve their effective implementation. Varying degrees of consensus and conflict were identified between stakeholders from different sectors. There was clearly, however, considerable support for implementing multi-functional coastal defence structures that can deliver secondary benefits – particularly ecological secondary benefits – in place of traditional single-purpose structures. The provision of habitat for rocky shore communities and species of conservation interest, and the provision of refuge for exploited species were ranked overall as the highest priority secondary benefits that could feasibly be delivered by multi-functional structure designs. This is valuable information for informing marine and coastal planning decisions that seek to balance environmental, social and economic priorities. A defining principle for the effective conservation of wild living resources (Mangel et al. 1996) is that it takes account of the motives, interests and values of all users and stakeholders, *but not by simply averaging their positions* (see also Layzer 2008). The modified Delphi technique was an effective means of synthesising information and expert judgements on this complex problem. The findings presented here will support progress towards wide-scale and effective implementation of ecologically-sensitive design of artificial coastal defence structures that are becoming ubiquitous features of urban coastlines. It may further be reasonable to apply these findings to the various other engineered structures – for oil and gas exploration, renewable energy generation, navigation, mariculture and recreation – that are proliferating in the marine environment globally (Dafforn et al. 2015, Firth et al. 2016a).

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Supporting Online Material (SOM)

SOM Table 1 Number of questionnaire respondents from each sector group.

Sector	Number of respondents
Academic Non-specialist (ANS)	20
Academic Specialist (AS)	5
Conservation (C)	14
Ecological Consultant (EcC)	15
Engineering Consultant (EnC)	6
Local Authority (LA)	5
Statutory Bodies* (SB)	16
Public / Unknown (P)	37
N	**118**

*Statutory Bodies – Coastal Management and Nature Conservation

SOM Table 2 List of considerations for planning coastal defence works presented to the Delphi panel in Round 2. The panel was asked to rank the considerations in order of priority (1 = 'High priority', 20 = 'Low priority').

CONSIDERATION	**RANK (1-20)**
Justification (i.e. considered necessary, supported by SMP and Coastal Strategy)	
Fit for purpose (i.e. provides adequate, appropriate and efficient protection over the required timeframe)	
In line with environmental legislation and planning guidelines	
Part of a sustainable strategy	
Cost and funding	
Unintentional alteration to coastal processes (i.e. changes to sediment and flow dynamics not intended as part of the defence function)	
Opportunities for research and development (e.g. new engineering solutions, experimental units for investigating marine/coastal ecology)	
Positive socio-economic impacts on local communities and businesses (e.g. through enhanced amenity, recreation, fisheries, navigation, tourism, employment, etc.)	
Negative socio-economic impacts on local communities and businesses (e.g. through reduced amenity, recreation, fisheries, navigation, tourism, employment, etc.)	
Opportunities for education and outreach	
Impact on landscape	
Culture and heritage	
Public safety (i.e. during construction and operation, rather than as a result of the defence function)	
Community support	
Carbon footprint	
Positive ecological impacts as a result of defence function (i.e. protect/extend existing sedimentary and hinterland habitats and species)	
Positive ecological impacts as a result of novel habitat (e.g. enhanced connectivity/resilience of rocky habitats, habitat for exploited species, habitat for species of conservation concern, habitat heterogeneity, etc.)	
Negative ecological impacts during construction and operation (e.g. loss/disturbance of habitats/species, facilitate spread of invasive non-native species, etc.)	
Negative ecological impacts as a result of extraction and transport of raw materials	
Multi-functionality (i.e. provides secondary ecological and/or socio-economic benefits)	

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SOM Table 3 List of potential secondary benefits that can be gained from multi-functional coastal defence structures presented to the Delphi panel in Round 2. The panel was asked to rank the considerations in order of priority (1 = 'High priority', 20 = 'Low priority').

POTENTIAL SECONDARY BENEFITS	**RANK (1-20)**
Improve funding potential	
Foster community support	
Fulfil requirements of environmental legislation and planning guidelines	
Avoid costs of clean-up operations (i.e. following flood events/storm damage)	
Opportunities for research and development – new engineering solutions	
Opportunities for research and development – investigating marine/coastal ecology	
Positive feedback in stability of structure (i.e. reduce maintenance requirements)	
Reduced carbon footprint / carbon sequestration	
House other technologies (e.g. turbines, masts, etc.)	
Positive socio-economic impacts on local communities and businesses (e.g. through enhanced amenity, recreation, fisheries, navigation, tourism, employment, etc.)	
Wider economy (e.g. through increased land use potential, wider employment, etc.)	
Opportunities for education and outreach	
Enhanced/safeguarded landscape	
Enhanced/safeguarded culture and heritage	
Enhanced/safeguarded public safety (i.e. in terms of interaction with the structure, rather than as a result of the defence function)	
Positive ecological impacts as a result of defence function (i.e. protect/extend existing sedimentary and hinterland habitats and species)	
Positive ecological impacts as a result of novel habitat (e.g. enhanced connectivity/resilience of rocky habitats, habitat for exploited species, habitat for species of conservation concern, habitat heterogeneity, etc.)	
Divert pressure from natural systems (i.e. by providing access for recreation, navigation, fisheries, research, etc.)	
Compensatory habitat creation	
Enhanced biosecurity (i.e. discourage spread of invasive non-native species)	

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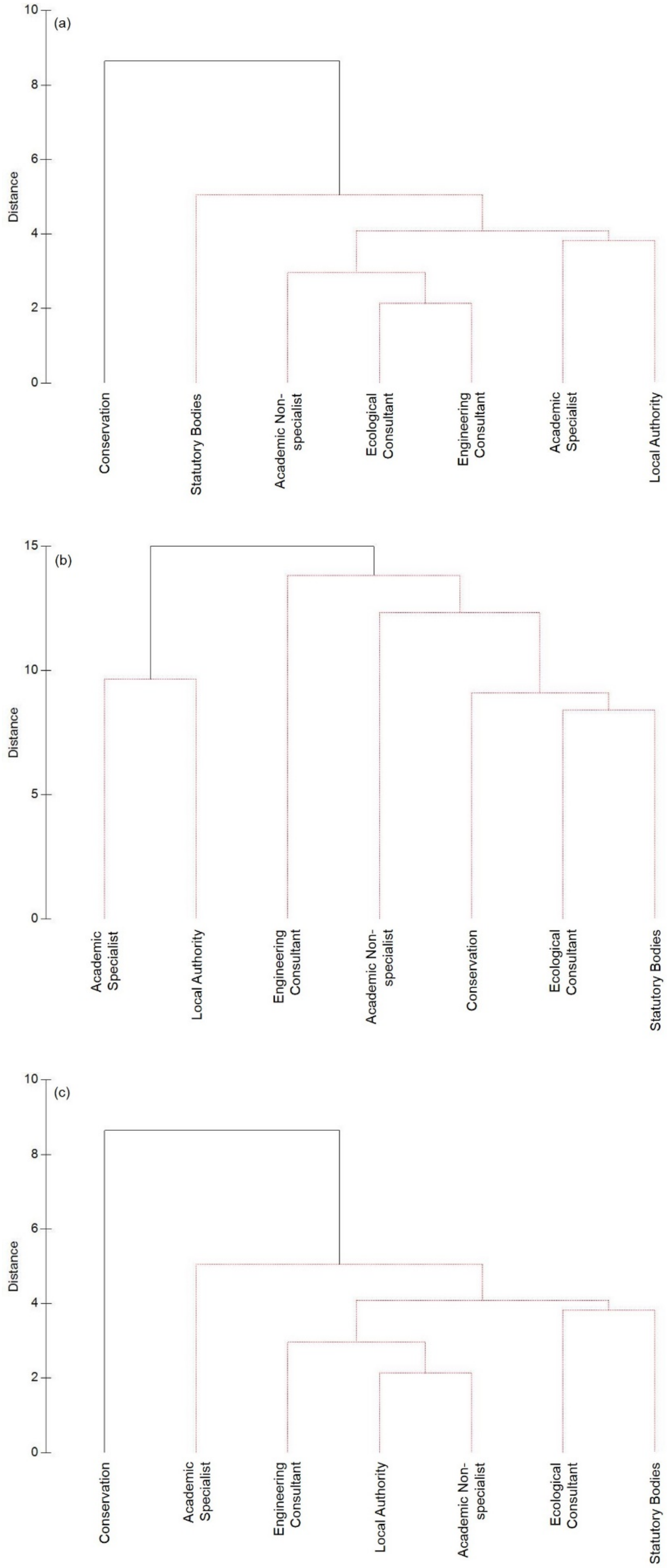

SOM Figure 1 Hierarchical clustering of mean sector scores (inverted ranks, i.e. 15/10 = high, 1 = low) assigned to (a) considerations for planning coastal defence works (*preferred* order of priority), (b) potential secondary benefits and (c) reasons for building them into developments by the Delphi panel.

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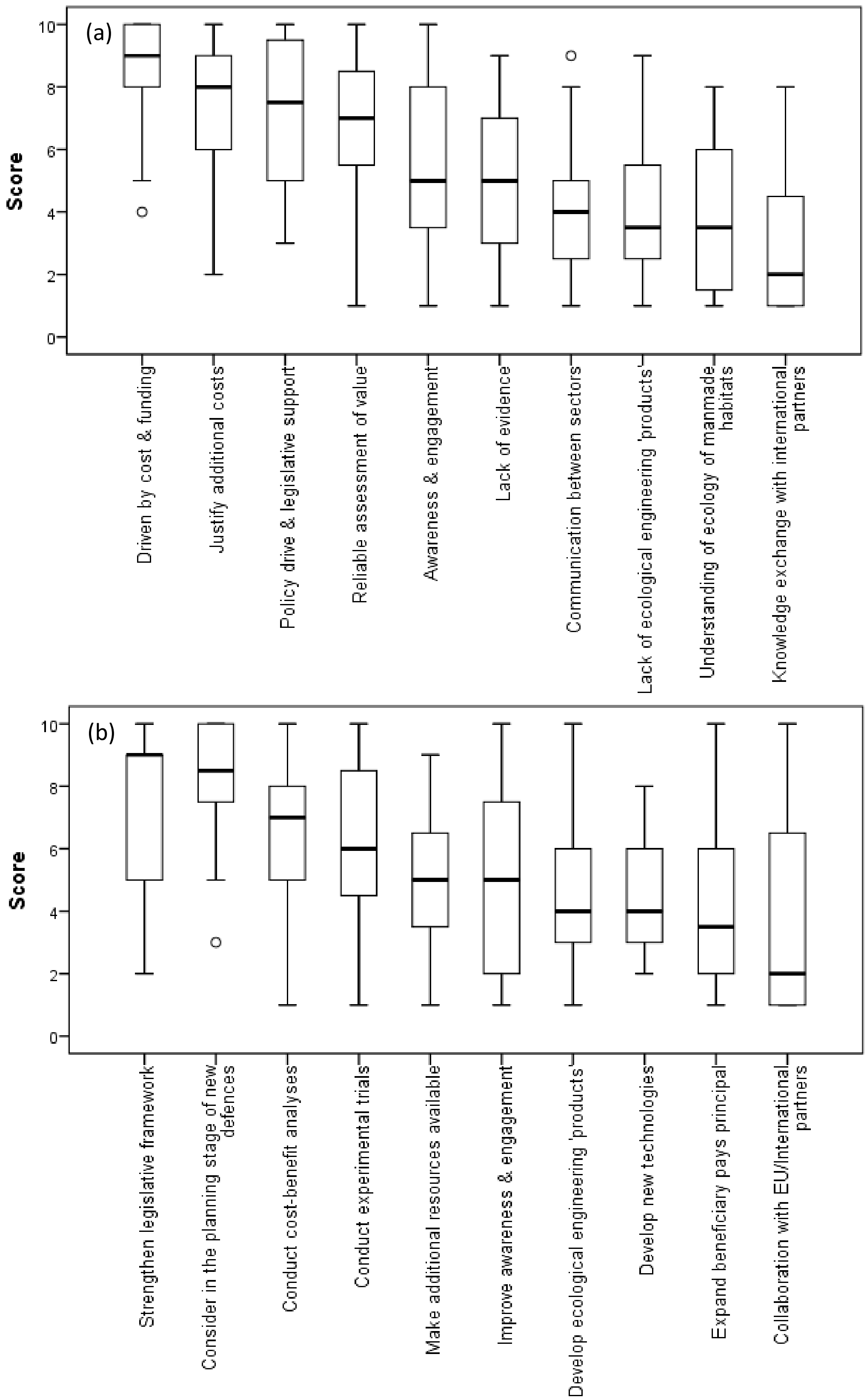

SOM Figure 2 Median scores (inverted ranks, i.e. 10 = high, 1 = low) assigned to (a) barriers to implementation and (b) suggestions for moving forward by the Delphi panel, with interquartile ranges (box), maximum/minimum scores (whiskers), outliers > 1.5 x interquartile range (○) and extreme outliers > 3 x interquartile range (⋆).